7.0 CONCLUSIONS

The conclusions of the technology evaluation, as they relate to the demonstration project objectives, include:

Primary Conclusions

P1 Evaluate the flow sensor's ability to detect the horizontal extent of the GCW groundwater circulation cell based on a change in the groundwater velocity criterion of 0.1 foot per day (0.03 meter per day)

- During the GCW circulation operation mode, the groundwater velocities measured by all seven sensors increased by more than 0.1 ft/day, indicating that (1) the sensors were within the circulation cell established by the GCW, and (2) the horizontal extent of groundwater circulation was greater than 15 feet. Furthermore, the groundwater flow direction data suggest that groundwater in the upper portion of the treatment zone generally flows radially away from the GCW and that groundwater in the bottom of the treatment zone generally flows radially towards the GCW. This flow direction data further support the establishment of a circulation cell and that all the flow sensors are within the horizontal extent of groundwater circulation cell.

- The data from the four modes of GCW operation suggest that the flow sensors are responsive to changes in groundwater flow conditions and can be used to help define and evaluate the three-dimensional flow pattern created by the GCW. The immediate response of the sensors to changes in GCW operation suggest that the groundwater circulation cell is established within hours instead of days. Additionally, the velocity data from the flow sensors suggest that the GCW circulation flow was generally constant during operation in the circulation mode.

Secondary Conclusions

S1 Evaluate the reproducibility of the groundwater velocity sensor data

- The reproducibility of the sensors during steady state conditions ranged from 0.1 to 23 percent with an average of 1.9 percent and a standard deviation of 3.8 percent.

S2 Evaluate the three-dimensional groundwater flow surrounding the GCW

- Groundwater flow patterns, as measured by the flow sensors, were documented for each of the four GCW operational modes and are depicted graphically to illustrate general flow patterns in the vicinity of the GCW during each mode of operation.

S3 Document the operating parameters of the GCW

- GCW pumping rate, duration of system operation, and GCW shutdowns were documented for each of the four modes of operation:

GCW Operational Mode	Pumping Rate	Duration of Operation	GCW Shutdowns
Circulation	4 gpm	July 10 – 28, 2000	1 shutdown for mechanical maintenance
Pump and Treat	4 gpm	August 2 – 29, 2000	7 shutdowns for mechanical repairs
Aquifer Hydraulic Testing	Various	September 13 – 19, 2000	None
Natural Conditions	No pumping	GCW not operated	GCW not operated

S4 Document the hydrogeologic characteristics at the demonstration site

- Natural groundwater flow velocities at the CCAS Facility 1381 site are very low, ranging from 0.03 to 0.21 ft/day (0.009 to 0.064 meter/day).

- The conductivity of the aquifer at the Facility 1381 site decreased with depth. Based on aquifer hydraulic test data, the hydraulic conductivity ranges from 43 to 53 ft/day (1.5×10^{-4} to 1.9×10^{-4} cm/s) for the shallow zone (upper 7 feet or 2.1 meters) and 5 to 10 ft/day (1.8×10^{-5} to 3.5×10^{-5} cm/s) for the deeper zone (7 to 25 feet deep or 7.6 meters). Storativity of the lower aquifer zone ranges from 0.006 to 0.007 and specific yield ranges from 0.06 to 0.09. The average anisotropic ratio (that is, the ratio of horizontal to vertical hydraulic conductivity) is 2.4, based on steady-state dipole flow test interpretation.

Additional findings and observations based on the EPA demonstration of the flow sensors include:

- According to the developer, the flow sensors measure flow in the a 3.3 cubic feet [1 cubic meter] area volume immediately surrounding the sensor,) and are subject to local heterogeneities. Complex site hydrogeological conditions may require a large number of flow sensors to adequately define the circulation cell and characterize flow patterns.

- To more fully evaluate the three-dimensional flow surrounding this GCW, additional sensors should have been installed at varying distances and depths from the GCW. Flow sensors should be installed at upgradient, downgradient, and cross-gradient locations at a minimum of three different distances from the GCW. The flow sensors also should be installed at three different depths corresponding to shallow and deep GCW screens as well as in the middle portion of the monitored zone between the two screens. The shallow sensors should be installed a minimum of 5 feet (1.5 meters) below the water table, which would minimize the impact of temperature variations caused by the vadose zone. Only seven sensors were installed for this project because preliminary modeling indicated that the circulation cell would be smaller than what was actually observed.

- HydroTechnics recommends installing the flow sensors with five feet (1.5 meters) of submergence because the shallow portion of the groundwater will heat up during the day, creating a thermal gradient that the sensor measures as water flow. For the EPA demonstration, the shallow sensors were installed with less than 5 feet of submergence because preliminary modeling indicated that there would not be significant flow deeper than 3 feet (1 meter) into the formation. Data from the shallow sensors were successfully corrected by subtracting the background temperature gradient.

- HydroTechnics recommends allowing at minimum of 7 days for the sensors to come to thermal equilibrium. During the EPA demonstration, short-term aquifer tests resulted in large but short-term changes in groundwater flow, that were successfully measured by the flow sensors.

- The cost of a single flow sensor was $2,500. The total cost for the seven sensors, sensor data analysis for a period of 1 year, and installation was $70,000 for this project. Costs at other sites may vary depending on installation depth and subsurface conditions.